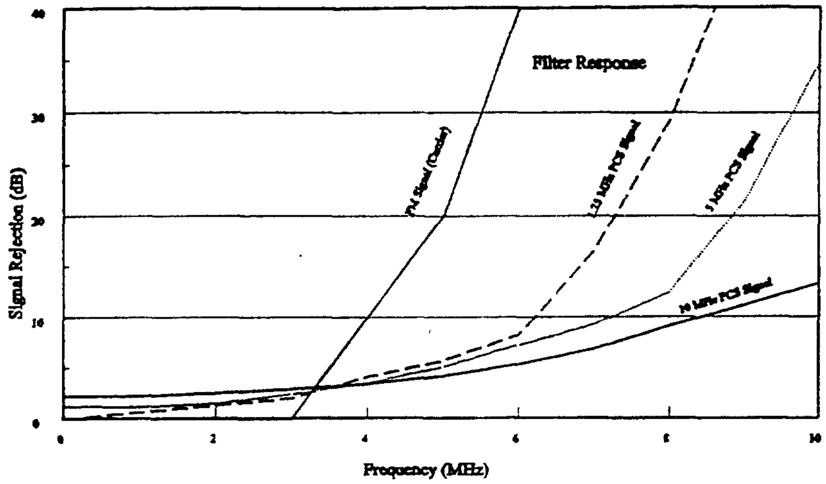


Figure A-16 Filter Selectivity Factor "Se" (Sharp FM Receiver Filter)

## A-14 Co-channel Intercarrier Beat Interference

Beat interference occurs when the carrier of a (nearly exactly) co-channel FM signal is demodulated to produce an interfering tone into a derived VF or data channel in the baseband of the victim receiver.

The RF carrier power in an FM signal modulated by band-limited white noise simulating busy-hour traffic is given by the following:

No Emphasis:

$$Carrier\ Power\ (dBm) = P_t - 10\log\left(\frac{4.34\ \Delta F^2}{f_{max} \times f_{min}}\right) \tag{A-18}$$

ITU-R Emphasis:

$$Carrier\ Power\ (dBm) = P_t - 10\log\left(\frac{1.99\ \Delta F^2}{f_{max} \times f_{min}}\right) \tag{A-19}$$

where

$P_t$ = RF total transmit signal power (dBm)
$\Delta F$ = RMS RF busy-hour carrier deviation (kHz)
$f_{max}$ = highest baseband frequency (kHz)
$f_{min}$ = lowest baseband frequency (kHz)

The total receiver baseband beat interference noise power in a message channel is given by the following:

$$-\frac{S}{I} = N\,(dBm0) = -3 - \frac{C}{I} + 20\log f - 20\log d + E \tag{A-20}$$

where,

| | | |
|---|---|---|
| S/I | = | S/N in a derived message channel due to the interference ( dB ) |
| C/I | = | difference in power between desired signal's carrier power and interfering signal's carrier power ( dB ) |
| f | = | baseband frequency at which beat interference occurs ( kHz ) |
| | = | difference between desired signal's carrier frequency and interfering signals carrier power ( kHz ) |
| d | = | per-channel RMS frequency deviation ( kHz ) |
| E | = | victim receiver de-emphasis value at frequency f ( dB ) |

Total beat noise (in dBm0) is the sum of the values from Figures A-17 and A-18 minus the value of C/I(dB). The noise in dBm0 may be converted to noise in pWp0 as follows:

$$N(dBrn0p) = 90 - 2.5 + N(dBm0) = 87.5 + N(dBm0) \quad \text{(A-21)}$$

$$N(pWp0) = 10^{\frac{N(dBrn0p)}{10}} \quad \text{(A-22)}$$

The "dBm0" measurement is a "flat" (unweighted) measurement. The "p" measurement denotes "psophometric" weighting. Note the following Section A-15 for background on the above conversion process.

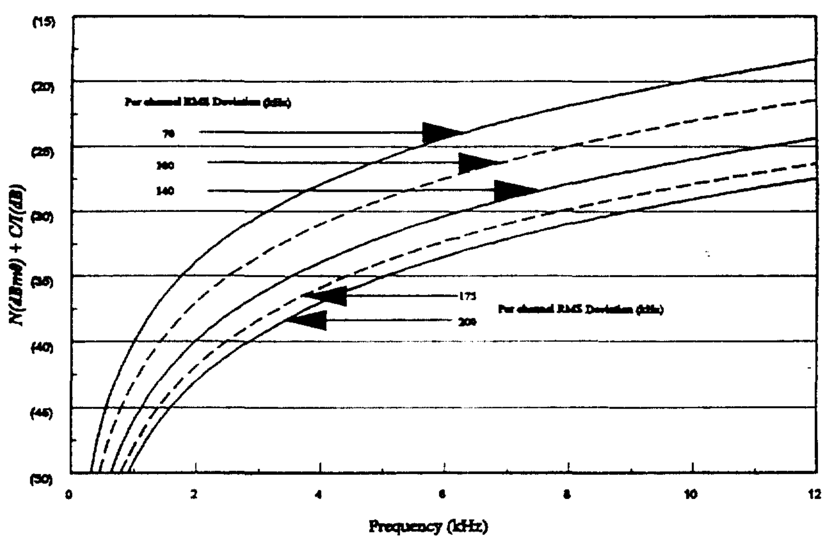


Figure A-17 Co-channel Intercarrier Beat Interference

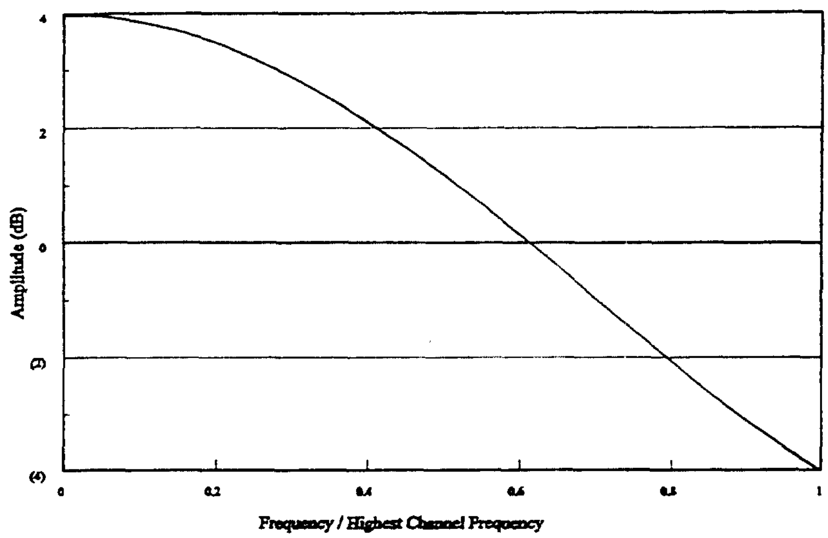


Figure A-18 ITU-R De-emphasis Values

## A-15 Noise Measurements and Objectives

The ratio of two powers (*e.g.* device input power $P_I$ and output power $P_0$) is generally measured as a neper or a decibel.

$$
\begin{aligned}
Neper &= \ln\left(\frac{E_0}{E_I}\right) = 0.5\ln\left(\frac{P_0}{P_I}\right) \\
Decibel\ (dB) &= 10\log\left(\frac{P_0}{P_I}\right) = 20\log\left(\frac{E_0}{E_I}\right) \qquad \text{(A-23)} \\
X(neper) &= (0.1151)\,Y(dB) \\
Y(dB) &= (8.686)\,X(neper)
\end{aligned}
$$

where $E_0$ is the output voltage and $E_I$ is the input voltage, and the device impedance at input and output are identical and purely resistive. Nepers are especially useful in working transmission line and generalized network problems where voltage transfer functions are used. Decibels are especially well suited for practical noise measurements.

A relative measurement in dB can be changed to an absolute power measure by arbitrarily specifying a reference power. The most common absolute power measurement units are dBm (power referenced to 1 mW) and dBrn (power referenced to a reference noise of 1 pW at a reference frequency of 1 kHz). Since dBrn is used exclusively for North American voice frequency noise measurements, which are often weighted, a reference frequency is included in the definition. The reference frequency is significant with noise weighted power measurements (C-message or psophometric) since weighting changes the power passed through the weighting network except at the reference frequency. If P is a measured power in mW,

$$dBm = 10\log\left(\frac{P}{1\ mW}\right) = 10\log\left[P(mW)\right]$$

$$dBrn = 10\log\left(\frac{P}{1\ pW\ referred\ \ to\ a\ reference\ \ frequency}\right) \tag{A-24}$$

$$= 10\log\left[P\,(pW\ referred\ \ to\ a\ reference\ \ frequency\ )\right]$$

$$X(dBm\ ) = Y(dBrn\ ) - 90\ dB$$

$$Y(dBrn\ ) = X(dBm\ ) + 90\ dB$$

Power levels are often measured using a high-impedance ac voltmeter calibrated using a sine wave delivering 1 mW of power to a 600-ohm resistor. If this voltmeter is bridged across a resistive circuit with 600-ohm impedance, delivered sine wave power is read directly on the meter. If the meter is bridged across a resistive circuit of impedance R, the meter reading must be corrected to account for the change in circuit impedance. If the meter is calibrated such that 0 dBm occurs for 0.775 VAC across 600 ohms, then the following correction factor may be used:

$$X\,(dBm\ ) = dBV\ (\ meter\ \ reading\ \ ) + CF\ (\ correction\ \ factor\ \ )$$

$$CF = 10\log\left(\frac{600}{R}\right) \tag{A-25}$$

Also, if the sine-wave calibrated meter is average responding and is measuring Gaussian "white" noise, 1.0 dB must be added to the meter reading to account for the change in meter calibration factor.

Noise power weighting is an attempt to qualify a telephone listener's or video viewer's subjective evaluation of circuit noise. The weighting filter is placed between a circuit being monitored and wide-band ac voltmeter measuring the circuit noise. The filter places difference emphasis or "weight" to different spectral frequencies. The concept of weighted noise measurements is based on the observation that not all noise frequencies of the same power level cause the same awareness in (annoyance to) the listener or viewer. The effect of the weight filter depends greatly on the type of interference. Noise in telephony channels is generally measured using C-message (IEEE[5]) or ITU-T[6] psophometric (ITU-T[7]) weighting networks.

In an analog message system, VF and data signals pass through strings of amplifiers, pads (attenuators), filters, and other active and passive devices having gains or losses. To facilitate exacting alignment, quality

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5 *IEEE Standard 743-1985 – IEEE Standard Methods and Equipment for Measuring the Transmission Characteristics of Analog Voice Frequency Circuits.*

6 ITU-Telecommunications, formerly CCITT.

7 "Recommendation G.212 – Hypothetical reference circuits for analogue systems", *International analogue carrier systems, Transmission media – characteristics*, CCITT (ITU-T), Geneva, 1985.

"Recommendation O.41 – Psophometer for use on telephone-type circuits", *Specifications for measuring equitpment*, Volume IV, CCITT (ITU-T), 1989.

(noise, crosstalk, *etc.*), and (in FM radio links) deviation measurements and adjustments, the transmission level point (TLP) concept has been developed. The actual transmission level (-16 dBm in, +7 dBm out for a 1 kHz test tone at a 4-wire VF channel interface, for example) is referenced to a 0 dB TLP (0 dBm0 in and out, in the above VF interface example). This reference level is also variously noted as a "0 TTL", "0 TPL", or "0 dBr" point. In the example, -16 dBm actual test tone level = 0 TLP (0 dBm0, 0 dBr). If a 9.6 kb/s -13 dBm0 (-13 TLP, -13 dBr) data signal was applied at this VF input, its actual measured level would be -16 dBm - 13 dBm0 = - 29 dBm.

It is noted that although the above levels are at VF frequencies, the corresponding signal power at any given point in an FM-FDM radio baseband will (except perhaps for an orderwire) be at some higher carrier frequency. This signal power is also computed and measured as above.

The same relationships apply for conversion of weighted measurements such as dBmc, dBmp (dBp), dBrnc, and dBrnp. If a 0 dBm test tone is applied at the 0 TTL point or 0 TLP, the signal level in dBm and the TLP are numerically equal throughout the system. Unless otherwise specified, the TLP is determined with a test tone which was caused by or will cause a reference frequency (800 or 1000 Hz) test tone at a voice channel. If a system is properly aligned and a test point is an established TLP, the TLP of any other test point following that test point is established by determined the test-tone level gain between the test point whose TLP is established and the test point whose TLP is desired. The TLP of the second test point is the algebraic sum of the TLP of the first test point and the test-tone level gain or loss from the first test point to the second. ITU-T (CCITT) systems often use "dBr" rather than "dB TLP".

In wideband multichannel FDM telephony systems, noise is generally specified as a signal-to-noise (S/N) ratio, noise power ratio (NPR), or (during idle periods) baseband intrinsic noise ratio (BINR). S/N is the decibel ratio of the level of the reference test tone (1000-Hz 0-dBm0 or 800-Hz 0-dBr sine wave) to the noise in a nominal 3100 Hz (300 to 3400 Hz) bandwidth voice-frequency telephone channel. To test the noise performance of these wide-band systems, broadband white Gaussian noise is used to simulate active (busy-hour) channel conditions. A noise generator (transmitter) produces a random noise voltage having a uniform power spectrum versus frequency characteristics. This noise is passed through high- and low-pass filters to shape the spectrum to conform to the nominal FDM baseband (excluding pilots). The signal is then passed through several bandstop filters, which have typically 80 dB of slot rejection in a narrow frequency slot when switched on. The correct composite baseband transmit level (*see*, Section 2.2 of this Bulletin) is applied to a system baseband using calibrated attenuators. Automatic level control compensates for filter insertion loss when bandstop filters are turned on. The baseband at the receive end of the system is applied to a noise receiver. The receiver is used to measure the change in noise level as the various bandstop filters are switched out and in. The receiver is typically an insertion loss type that operates at constant gain. Relative measurements are made using a calibrated attenuator at the front of the device. The receiver has a variable center frequency bandpass characteristic that is much narrower than the transmit bandstop filter. The generator is set to apply noise loading level to simulate the appropriate number of telephones. For systems greater than 239 channels, the noise loading is -15.0 to -19.6 dBm0, depending upon VF/data baseband mix, per voice channel. The output of the system is applied to the noise receiver. All transmit bandstop filters are turned off (switched out of the circuit) and the appropriate bandpass receiver filter is turned on. The receive input attenuator is adjusted so that a reference noise reading is obtained. The corresponding transmit bandstop filter is turned on and the receive input attenuator is readjusted to restore the reference noise level. The difference in attenuator settings is the NPR for the particular noise loading and baseband slot frequency. (BINR is similarly measured, but with the transmit baseband load off.) This measurement defines noise introduced by the transmission system into a baseband frequency slot, which when transmitted is relatively free of noise. If the second noise measurement is taken while baseband noise loading is applied at the transmit end, an NPR measurement is obtained. A Noise Power Ratio (NPR) is the decibel ratio of the noise level in a measuring channel with the baseband fully noise loaded to the level in that channel, with all of the baseband noise loaded except the measuring slot. The NPR is a measure of thermal, echo, intermodulation, and other distortions and noise sources contributed by the transmission medium. If the second noise measurement is made with the transmit baseband terminated in a characteristic impedance resistor (typically 75 ohms) rather than the noise generator (*i.e.*, no transmitted baseband load), a BINR (idle noise) measurement is obtained. A BINR is the decibel ratio of noise in a test channel, with all noise loading removed. The BINR is a measure of all transmission-induced noise except intermodulation noise. NPRs and BINRs can be converted to an S/N ratio as follows (NPR will be used exclusively; the same formulas apply, of course, for BINR):

$$\begin{aligned}\frac{S}{N}(dB) &= -N\,(dBm0) \\ &= -NLR\,(dBm0) + BWR + NPR\,(dB)\end{aligned} \tag{A-26}$$

where

| | | |
|---|---|---|
| NLR | = | noise loading ratio used to obtain NPR (dBm0) |
| | = | $-1 + 4\log(N)$, $12 \le N \le 239$ per ITU-T/ITU-R[8] |
| | = | $-1$ to $-5.6 + 4\log(N)$ per AT&T/FCC |
| | = | $-15 + 10\log(N)$, $N \ge 240$ per ITU-T/ITU-R |
| | = | $-15$ to $-19.6 + 10\log(N)$, $N \ge 240$ per AT&T/FCC |
| N | = | number of FDM telephone channels in baseband |
| BWR | = | bandwidth ratio (dB) |
| | = | 10 log [ baseband bandwidth / channel bandwidth ] |
| | = | $10\log[(f_{max} - f_{min}) / 3.1\text{ kHz}]$ |
| $f_{min}$ | = | lowest baseband FDM frequency (kHz) |
| $f_{max}$ | = | highest baseband FDM frequency (kHz) |
| NPR | = | 10 log [ channel noise load/measured channel noise ] (dB) |

These formulas produce an unweighted S/N ratio. The S/N ratios are converted conventionally to weighted measurements by adding white noise weighting conversion factors of 1.7 dB for C-message weighting and 2.5 dB for psophometric weighting.

### A-15.1 System design objectives

Microwave systems are designed by estimating typical conditions and worst case conditions. An FM-FDM microwave radio normally has a large received signal level (RSL). When it does, the radio performance is only limited by the inherent noise of the multiplex and radio equipment. That noise represents the typical system performance. System Noise Objectives characterize this unfaded RSL performance.

As with all radios, the microwave radio received signal level will vary from time to time. As the RSL decreases (fades), the radio (thermal) noise in an FM receiver increases. The systems are designed to reduce this noise to an acceptable level for a high percentage of time. The thermal noise is a function of the number of multiplex channels, receiver noise figure and the FM deviation. This noise performance is easily calculated. The microwave RSL seldom varies (fades) much, but when it does, the noise in the link is deemed unusable. That point is typically 55 dBrnc0 (flat S/N of about 33 dB) for AT&T multiline systems or about 58 dBrnc0 (flat S/N of 30 dB) for other links. If the radio fades to greater noise that this specified, the link is deemed unacceptable for service and therefore mutes (or is switched off line). Under normal circumstances 30 dB S/N would not be tolerated by many customers. In practice the deep fades which cause such outage are very short in duration (less than a second) and several minutes to hours apart. The percentage of time that the system is free of outage is

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[8] ITU-R, formerly CCIR; ITU-T, formerly CCITT

determined by engineering to path reliability objectives.

Keep in mind that even when the system experiences no short-term outage, it may not be meeting its noise objectives. Both unfaded noise and outage objectives must be met for a well functioning FM-FDM analog system.

For digital systems, since the circuit noise is independent of typical radio performance, only outage objectives need be considered. Until the digital receiver RSL fades to within 6 to 12 dB of its dynamic outage ($10^{-3}$ BER) threshold, for all practical purposes the radio transmission is essentially error free. This gives the digital radio systems more engineering options. On short paths, fade margins can be reduced by allowing interference to be higher than on long paths or by reducing transmit levels to reduce interference into other systems.

These discussions have not mentioned video systems. Of course, if the video is carried over digital circuit, no distinction is necessary. However, for analog FM radios, one might wonder about video performance. One need not be concerned. Any system designed to meet 600 channel telephony noise and outage objectives will also exceed any video noise performance standards providing, of course, that its baseband will accommodate the wideband video signal.

A-15.2 Path reliability (outage) objectives (faded noise performance)

AT&T originally established worst case two-way end to end long haul (6,400 km) and short haul (400 km) system user objectives which would not be exceeded more than 0.02% of the time when averaged over several years on a system basis. The worst case user performance was limited directly by the radio system performance. The following system outage objectives are typically used:

S/N = 30 dB unweighted (FM-FDM analog with or without emphasis)
BER = $10^{-3}$ (digital)

AT&T's objective was to exceed the two-way outage objectives, on the average, more than 0.02 percent of any year (1.75 hours total). This is equivalent to an average end to end system two-way availability of 99.98%. Outage allocations were as follows:

a. 0.01 percent two way short-term outage due to multipath fading

b. 0.005 percent two way long-term outage due to flat obstruction (earth bulge) fading

c. 0.005 percent two way long-term outage due to equipment failure and maintenance

For paths operating above 10 GHz, rain attenuation fading is often the dominant fading mechanism. For these paths, one way and two way fading objectives are the same and objectives for such "local grade" high frequency links (with few tandem connections) are relaxed below these long- and short-haul objectives.

For paths operating below 10 GHz, fading is primarily due to multipath. Two-way objectives apply to a duplex path. Multipath is generally calculated in a particular transmitter to receiver one-way direction. Deep fading is relatively rare and uncorrelated with regard to location or direction of propagation. Therefore, the two way objective is split equally by direction of transmission

For systems operating below 10 GHz, the per hop one way propagation reliability objective is

(100 - [ 0.01 / ( 2N ) ] ) % = (100 - 0.005/N) % = 99.995% (1,600 sec/yr outage) per system

N = number of cascaded hops
= 10 for short haul system, or 99.9995% (160 sec/yr outage) per hop
= 75 for long haul system (only ½ of the 150 hops are fading), or 99.99993% (20 sec/yr outage) per hop

The reliability objective for a very short haul (<10 hops) system is relaxed to 99.999% per hop.

A-15.3 Adjacent channel threshold degradation

Outage objectives set a performance threshold to be achieved a specified percentage of time. Interference due to foreign systems must be controlled to avoid significant degradation of the designed path performance. Typically paths are designed to achieve a minimum performance at a specified RSL without any foreign radio interference. The foreign radio interference is then considered and engineered in such a way that the following objectives are degraded no more than the following:

30 dB S/N without interference degraded to 29 dB S/N (1 dB) with interference present (FM-FDM analog)

$10^{-6}$ BER static threshold RSL without interference degraded 1 dB with interference present (digital)

A-15.4 Noise objectives (unfaded noise performance)

Noise objectives for long haul and short haul radio systems have been developed for several years. Traditionally, the typical worst case customer to customer AT&T noise objective was 26 dBrnc0.[9] However, in 1962 the typical long distance customer to customer noise was actually measured as a mean of 23.6 dBrnc0.[10] In 1964 the noise objective was changed to 23 dBrnc0[11] for customer to customer circuits from 112.5 to 447.5 km (181 to 720 miles) long to reflect the new measurements. This is the total noise the customer would normally hear due to all sources. It is equivalent to a flat signal to noise ratio of about 65 dB.

The significant sources of noise are due to Frequency Division Multiplex (FDM) equipment and the Frequency Modulation (FM) radio noise under normal (unfaded) conditions. Typical noise contributions may be estimated by using AT&T noise objectives.[12]

Virtually all radio systems being designed today would be characterized as short haul systems. Consider AT&T noise objectives applied to a simple short haul system (as used by AT&T and Bellcore) composed of 10 radio hops with multiplex termination:

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9 *Bell System Technical Journal*, March 1964, page 706

10 *Bell System Technical Journal*, March 1964, page 707

11 *Bell System Technical Journal*, March 1964, page 736

12 *Bell System Technical Journal*, September 1971, pages 2085 to 2116.

- Noise from a pair of channel, group, and supergroup multiplex units

$$= 31.2\ dBrnc0\ -\ 10\log(16) = 31.2 - 12.0 = 19.2\ dBrnc0\ = 74\ pWp0 \tag{A-28}$$

- Noise from a pair of wire line entrance links

$$= 28.0\ dBrnc0\ -\ 10\log(16)\ =\ 28.0 - 12.0\ =\ 16.0\ dBrnc0\ =\ 36\ pWp0 \tag{A-29}$$

- Noise from FM Radio Echo Distortion

$$3.7\ pWp0\ per\ hop \times 10\ hops\ =\ 37\ pWp0 \tag{A-30}$$

- Noise from the Radios

  Typical High Quality Radio NPR is 55 dB for a single hop.
  For a typical 300 channel system,

$$\begin{aligned} \frac{S}{N}(dB) &= NLR + BWR + NPR \\ &= [-15 + 10\log(300)] + 10\log\left[\frac{(1{,}300 - 60)}{3.1}\right] + NPR \qquad \text{(A-31)} \\ &= -9.8 + 26 + NPR \\ &= 16.2 + NPR = 16.2 + 55 = 71\ dB\ (flat) \end{aligned}$$

(The S/N = 16 + NPR and dBrnc0 = 72 - NPR conversions are essentially the same for channel capacities above 239 channels, these being the dominant point-to-point radios in the 2, 6, and 11 GHz bands).

Typical Single Hop Radio Noise (for 71 dB S/N) = 17 dBrnc0 = 41 pWp0

- Most NPR noise is one quarter intermodulation (IM) and three quarters fixed thermal noise like noise (FN). The FN adds on a 10 log N basis while the intermodulation adds on roughly a 14 log N basis (per AT&T long haul estimates[13]).

$$\begin{aligned} FN(10\ hops) &= 37.5 \times 10^{+1.0} = 375\ pWp0 \\ IM(10\ hops) &= 12.5 \times 10^{+1.4} = 314\ pWp0 \end{aligned} \tag{A-32}$$

- Assume all other systems cause negligible interference. Single hop adjacent channel noise (ACN)

[13] *Bell System Technical Journal*, September 1971, pages 2085 to 2116.

objective is 25 pWp0.

The total expected noise for the short haul system (10 hops of radios) under normal conditions is

| | Power (pWp0) |
|---|---|
| Multiplex Units | 74 |
| Wire Line Entrance Links | 36 |
| Echo Distortion | 37 |
| Fixed Noise | 375 |
| Intermodulation Noise | 314 |
| Adjacent Channel Noise | 250 |
| Total Noise | 1086<br>(31 dBrnc0,<br>57 db S/N) |

The above represent typical design objectives for end to end system performance.

The above numbers reflect realistic conditions. However, it is clear that the above number will miss the AT&T objective of 23 dBrnc0 customer end to end performance. They will just meet the worst case intercontinental noise objective.[14] Only 50% of the customers would rate this circuit as excellent.[15] The Bell System resolved this issue by inserting circuit attenuation. This Inserted Connection Loss (ICL) for 4 wire carrier facilities (including microwave) was calculated (Section 7, Transmission Considerations, AT&T Notes on Distance Dialing and Bellcore Notes on the Bell Operating Company Intra-Lata Networks) as follows:

$$\begin{aligned} ICL\,(dB) &= 0.4 + (2.4\times 10^{-3}\times D)\,, & \textit{kilometers} \\ &= 0.4 + (1.5\times 10^{-3}\times D)\,, & \textit{miles} \end{aligned} \qquad \text{(A-33)}$$

where,

D = airline distance

This provided 6.4 dB additional noise reduction for the 6,400 km (4,000 mile) reference circuit. This brings the long haul objective to within 0.6 dB of the 23 dBrnc0 typical customer objective.

14 *Bell System Technical Journal*, March 1964, pages 734 and 736.

15 *Bell System Technical Journal*, March 1964, page 723, Figure 2.

A-15.5 Adjacent Channel Noise (Under Unfaded Conditions)

Foreign radio systems can affect the noise performance of radio systems. This interference must be controlled to achieve the above objectives. Restating the previous discussion, the end to end objective for noise due to adjacent channel foreign radios is the following:

$$250\ Wp0 \;=\; about\ 24\ dBrnc0 \;=\; -64\ dBm0\ (unweighted\ ) \;=\; 64\ dB\ \frac{s}{n} \qquad \text{(A-34)}$$

This objective may be met by at least four different approaches:

*Option 1* Set each radio hop's performance based on the anticipated type of service:

-64 dBm0 - 10 log N (A-35)

N = number of typical cascaded hops
= 10 for short haul system
= 75 for long haul system (only one half of the 4,000 mile system hops experience interference)

*Option 2* Set each radio hop's performance based upon actual number of radio hops between circuit ends

-64 dBm0 - 10 log N (A-36)

N = typical worst case number of cascaded hops in the system channel

*Option 3* Measure existing typical worst case end to end system noise during busy hour traffic loading periods. Calculate adjacent channel noise which degrades measured noise by no more than one dB.

For a more detailed treatment of the above topics, see George Kizer, *Microwave Communication*, Iowa State University Press, 1990, Chapters 1 and 10.

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# Annex F

# PCS/POFMS Spectrum Sharing Considerations[1]

## F-1 Introduction

This annex addresses the specifics of the methods and procedures to be used for coordination of co-primary fixed and mobile services in the 2 GHz band (1850-1990 MHz).

## F-2 Background[2]

The FCC, in its Emerging Technologies proceedings and subsequent PCS rule making,[3] established Personal Communications Services (PCS), a mobile service, on a co-primary status with the Private Operation-Fixed Microwave Service (POFMS) in the 2 GHz band(s). Both licensed and "non-licensed" PCS operation have been approved. Non-licensed is non-coordinated,[4] with PCS/POFMS interference potentials resolved either through PCS operation of such low power as to not materially present a problem or through relocation of existing POFMS licensees. This annex treats only the requirements for coordinated PCS/POFMS spectrum sharing situations.

## F-3 Interference Potential Determination Factors

F-3.1 PCS System Loading.

For coordination purposes in determining interference potential between PCS and fixed microwave services, it shall be assumed that the maximum number of simultaneously transmitting mobiles or base station channels shall be 50% of the maximum capacity of the system,[5] as determined either by the maximum r.f. channel compliment or phone line interconnects of the base stations.[6]

*Example: (a) The PCS system is comprised of 100 base stations, each with a 12 channel maximum capacity. Thus, for coordination purposes, 1200*50%=600 simultaneous calls shall be assumed, distributed evenly among the system operating frequencies. (b) Each of*

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1 The procedures described in this Annex represent the first attempt to develop procedures for spectrum sharing between PCS and POFMS. Its application could result in either higher cost than necessary to clear PCS frequencies or excessive interference to incumbents. Anyone applying these procedures should report their experiences through TIA to the Chairman of TR-14.11.

2 Where the term "mobile" is used, either vehicular or hand-held portable is to be construed.

3 FCC Docket No. 92-333, *Notice of Proposed Rule Making*, "Amendment of the Commission's Rules to Establish New Personal Communication's Services", 16 July 1992.

4 "Non-licensed" PCS may early deploy some systems on a coordinated basis.

5 In cases where affected the microwave links are associated with safety, life and property, coordination based on a greater percentage of system capacity may be required. Also, for PCS systems with continuously transmitting base stations (independent of channel traffic), the station duty cycle is obviously 100%.

6 A ten channel maximum is assumed for typical base stations, with a 2% grade of service, Erlang B.

*the 100 base stations are to be equipped with only 6 telephone line cards. Thus, 100*6*50%=300 simultaneous calls are assumed.*

F-3.2 Coordination Distances.

The minimum coordination distance for PCS can be calculated using Equations F-3-1 through F-3-5. Table F-3-2 is an example of such calculations. The calculated distances assume a reference of 10 watts EIRP for a potential PCS interferer, with its antenna at 90 meter elevation, a microwave receiving site antenna at 172 meter elevation (average height of 2 GHz antenna) and a 200 kilometer path between them with a normal k=4/3 earth bulge obstruction between the two systems. As the PCS antenna height and power levels are changed, so too is the required coordination distance changed to reflect the expected change in propagation loss between them.[7]

$$D_{LT} = 2.56 \sqrt{(H_t)} \qquad \text{(F-3-1)}$$

$$D_L = 10^{\left(\frac{51.87 + P}{20}\right)} \qquad \text{(F-3-2)}$$

$$D_D = \frac{65 + 1.85\, D_{LT} + P}{0.106 \log(D_{LT} + 33.6) + 0.899} \qquad \text{(F-3-3)}$$

$$D_s = \frac{-19.9 + 0.12 \times D_{LT} + P}{0.1156 - 5.6\times10^{-5} \times D_{LT}} \qquad \text{(F-3-4)}$$

$$D = \min(D_L, \max(D_D, D_S)) \qquad \text{(F-3-5)}$$

where:

P = EIRP (dBm)
$H_t$ = Transmitting antenna height above average terrain along the path (meters). Use 5 meters for values less than 5 meters.
$D_L$ = Free space distance (kilometers)
$D_D$ = Diffraction distance (kilometers)
$D_S$ = Scatter distance (kilometers)
D = Coordination distance (kilometers)
$D_{LT}$ = Distance to horizon (kilometers)

7 2nd R&O, GEN Docket 90-314

| PCS EIRP (watts) | Base station antenna height above average terrain in meters | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 10 | 20 | 30 | 50 | 90 | 120 | 150 | 300 | 600 |
| 0.1 | 90 | 93 | 99 | 103 | 110 | 120 | 126 | 131 | 152 | 181 |
| 1 | 99 | 103 | 108 | 113 | 119 | 129 | 135 | 140 | 161 | 191 |
| 2 | 120 | 122 | 126 | 129 | 133 | 140 | 145 | 148 | 164 | 193 |
| 5 | 154 | 157 | 161 | 164 | 168 | 175 | 179 | 183 | 198 | 220 |
| 10 | 180 | 183 | 187 | 190 | 194 | 201 | 206 | 211 | 225 | 246 |
| 20 | 206 | 209 | 213 | 216 | 221 | 228 | 233 | 237 | 251 | 274 |
| 50 | 241 | 244 | 248 | 251 | 255 | 262 | 267 | 272 | 286 | 309 |
| 100 | 267 | 270 | 274 | 277 | 282 | 290 | 294 | 298 | 314 | 336 |
| 200 | 293 | 296 | 300 | 303 | 308 | 315 | 320 | 325 | 339 | 364 |
| 500 | 328 | 331 | 335 | 338 | 343 | 351 | 356 | 359 | 375 | 399 |
| 1000 | 354 | 357 | 361 | 364 | 369 | 377 | 381 | 386 | 402 | 425 |

**Table F-3.2**
**Coordination Distances in Kilometers**

### F-3.3 PCS system power aggregation

PCS licensees will typically employ numerous micro/macro cell subsystems within their licensed areas. Under certain conditions described below, aggregation of PCS transmitter powers may be done at the Center of a Defined Area (CDA) in order to simplify coordination procedures.

#### F-3.3.1 Aggregation methods

Center of a Defined Area (CDA) based aggregation of PCS transmitter powers is permitted when the boundaries of the coordinated service area subtend an angle less than "X" degrees with the subject microwave receiver location and the distance from the CDA to the service area boundry, on a line to the microwave receiver, does not exceed 25% of the distance from the boundry to the receiver. For angles exceeding "X" degrees, or distances greater than 25%, the service area may be further divided into a number of sub-areas that meet the criteria. Where the conditions for CDA based aggregation are not met, the interference from the PCS units in the service area must be determined by a statistical aggregation method.

The allowed included angle "X" is determined from the offset angle, $\theta$, which is equal to the minimum angular displacement from the centerline of the microwave antenna main beam to a point on the perimeter of the Defined Area. Then $X = 0.7\theta$ degrees for $\theta \geq 10$ degrees; $X = 5$ degrees for $\theta < 10$ degrees; and $X = 5$ degrees where $\theta$ is unknown.

Statistical methods for aggregating the PCS transmitter powers to a CDA may use any available information to determine the expected spatial PCS distribution, with a uniform distribution as default in absence of better information. A uniform distribution can be used in the absence of such information. Using this distribution, the aggregated interference can be determined using either analytical techniques or Monte Carlo simulation methods.

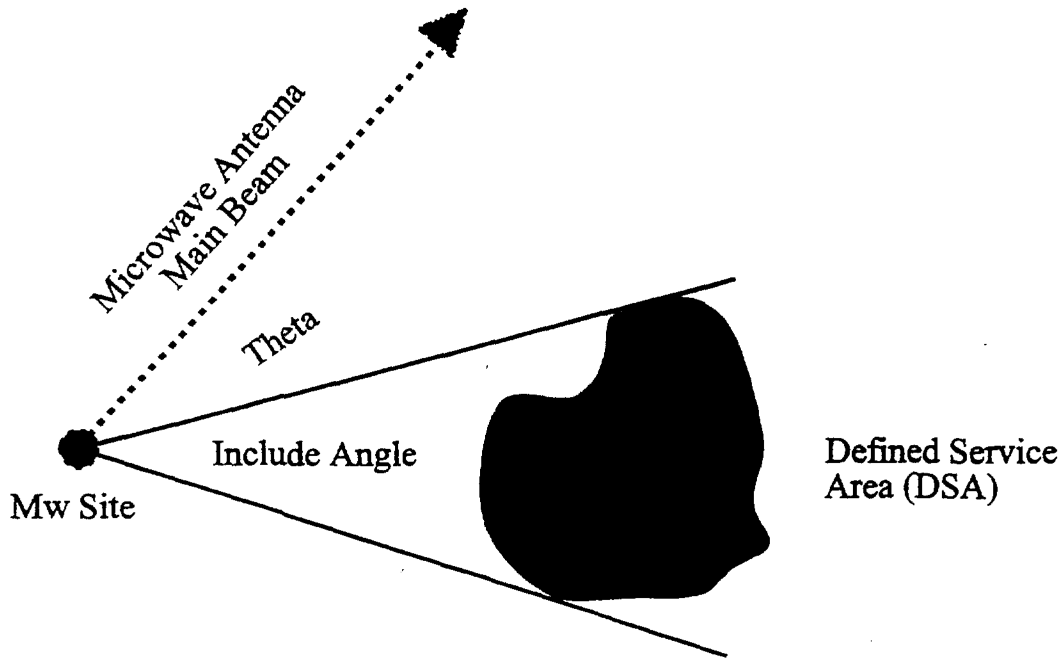


**Figure F-3.3-1 — Aggregation Angles**

F-3.3.2 PCS mobile units.

Mobile PCS units shall be aggregated at street level at the PCS service area CDA. "Street level" shall be interpreted as the average street level elevation for the expected PCS coverage area.

F-3.3.3 Portable aggregation factors.

F-3.3.3.1 Local in-building cells.

Portable units shall be aggregated at a height one floor above the intentional cell location. Appropriate above street height gain factors from Section F-4.5 shall be applied, either as an artificial adjustment to EIRP or to propagation loss.

F-3.3.3.2 Foreign in-building portable operation.

It is possible that users might initiate communications from higher level in-building locations to external base stations (*e.g.* 15th floor window to external 3rd floor or 30th floor roof base antenna), due to the "discovery phenomena",[8] even though that would not be a normal PCS coverage area. This shall be considered by assuming that 5% of the expected quantity of PCS portable units (see Section F-3.1 above) will operate in this mode, referring to the appropriate height gain factors of Section 4.5.

| System Type | Comment |
|---|---|
| Pedestrian only | Aggregate the 5% at the average floor height in the area |
| In-building only | Aggregate the 5% @ max floor + 1. |
| Both | Aggregate the 5% @ max floor + 1. |

F-3.4 PCS System Parameter Specification

It is expected that there will be a wide variety of PCS system types and that manufacturers and/or operators will need to supply sufficient definition of at least the following parameters:

F-3.4.1 Duplexing Method

Either frequency division or time division duplexing (FDD/TDD) shall be specified.

F-3.4.2 Peak and/or Average Transmission Power

Both operational peak and average transmitted power shall be specified for all transmitters,[9] assuming no system level power control effects (see Power Control).

F-3.4.2.1 Equivalent Isotropic Radiated Power (EIRP)

Where transmitter EIRP is different than the specified "transmitter power", it should be so specified, including any antenna pattern effects i.e. both gain and degree of directionality.

F-3.4.3 Multiple Access Method

The multiple access method shall be specified, being either FDMA, TDMA, CDMA or a hybrid, with enough detail such as to allow calculation of the necessary coordination parameters.

F-3.4.4 Channel Selection Method

The method of system selection of any of the FDMA/TDMA/CDMA/hybrid communication channels shall be specified. This may be either non-dynamic (*e.g.* fixed channels via (re)programming) or dynamic (*e.g.* channels selected based on some measured quality level). In either case, the range(s) of the possible channel selections and impact on resulting power spectral densities must be defined.

F-3.4.5 System Power Control

Most PCS systems employ some form(s) of transmitter power control on the mobiles (and sometimes

[8] The user discovers that communications is possible, though not contemplated by the PCS service provider.

[9] It is expected that often there will be differences in peak/average power between base stations, and mobiles, depending on system operation.

on the base stations as well). Thus, the average system operating mobile power will be less than maximum, as a function of the assumed mobile distribution around the "average" base station. Assuming, for instance, a $D^2$ propagation loss slope and a uniform area distribution of mobile units, the average transmit power will be ½ maximum (at the range limit). The PCS licensee should specify any different average mobile power level, as well as the method of determination.[10]

F-3.4.6 Power Spectrum

The basic PCS transmitted power spectrum should be defined in terms of dBW/4kHz with a given bandwidth, where the bandwidth is specified over "99%" of the spectral energy. Furthermore, the transmitted spurious emissions should be specified as well, typically in terms of meeting some emissions mask shape (this requirement will most likely be set by the FCC). Where special spectrum shapes are used, as for instance might result from implementation of notch filters, these should be so specified.

As part of the coordination process, the PCS system may be configured (see Channel Selection) in various fashions such as to either spread or concentrate the total system transmissions within a range(s) of frequencies. This may be done purposely for improved spectrum sharing reasons or for other reasons, such as frequency/channel reuse to achieve a certain PCS communication quality level. Expected spreading/concentrating should be specified in order to determine system or sub-system net power spectral density.

Net power spectral density emanation from a service area will be a function of the total number of operating transmitters. If a single PCS transmitter is being coordinated, then the peak transmitter power should be assumed on any operating frequency channel[11] for spectral power density calculations. Care should be exercised in determining multiple transmitter net spectral power densities as these conditions tend toward use of $N*P_{avg}$ rather than $N*P_{peak}$. For example, one 1-watt peak mobile on a 10 slot TDMA channel would imply use of 1 watt whereas 10 synchronized mobiles using the same channel would still result in an assumption of 1 watt net (as would any sub-multiple *e.g.* 5).

Total system/sub-system power spectral densities will be a result of a these and a number of additional factors above.

F-3.4.7 Additional PCS Coordination Parameters

- Applicant's name, address, phone number and designated contact.
- Site identification and coordinates.
- Frequencies and polarizations.
- Transmitting equipment manufacturer, model, type, stability, output power, emission designator/bandwidth, and type of modulation.
- Transmitter antenna manufacturer, model, types, patterns, gains, azimuths, height above ground level and ground elevation above mean sea level.

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10 Typically, this calculation would involve a distribution assumption of PCS mobiles in the operating area, with a maximum operating power level assumed for the farthest units and a minimum power assumed for the closest units and interpolated values in-between.

11 Though the assumption has been made (F-3.1) that 50% of the channels will be assumed operating and this would imply a peak-3dB factor, peak is believed appropriate to apply here.

F-3.5 PCS Usage Factor

Whereas microwave stations are on all the time (100% duty cycle), typical vehicular PCS systems will tend to have two peak usage periods (morning and early evening), lasting about 2 hours each and falling off greatly in between (to factors of less than 1/10 in the evening hours). Further, only the morning PCS use period will be of significant consequence, since microwave fading generally occurs during the 8 hour period after midnight. Thus, over the long term, PCS potential interference degradation to microwave availability will be 6 dB[12] less than a continuous duty PCS operation.

[The maximum allowed adjustment factor is capped at 6 dB pending further study.]

Experience with future PCS systems could modify this 6 dB factor. For instance, an office environment PCS system would be expected to peak later (after the vehicles arrive), resulting in a larger adjustment factor. As an example, if the PCS activity only occupies ½ hour of the 8 hour fading period, then the adjustment factor would be 12 dB. [The current cap will limit this to 6 dB.]

*The value of this adjustment factor needs to be considered in terms of the PCS periods, whether operation will be continuous or spurious, etc.), as well as how this activity will impact the nominal (unfaded) performance or the threshold performance of a route.*

## F-4 Propagation loss models

This section provides simple propagation models for first pass coordination calculations for PCS into the POFMS microwave system. These propagation models are useful where detailed building and terrain information are not available or to determine if more detailed information must be provided.

F-4.1 Introduction

Propagation in the transhorizon region can be characterized by smooth earth diffraction,[13] rough earth diffraction,[14] and forward scatter propagation.[15] Hufford *et. al.*, based on *NBS Tech Note 101*, attempts to combine these various propagation models and to provide transitions between them. Unfortunately none of these models adequatily takes into account an area ground "clutter" factor which would surround either

[12] Ref. TIA report TR14.11/94.1.25-100. 2 hours out of 8 hours corresponds to 6 dB. Variations in the expected morning PCS activity within the 8 hour fading period will correspondingly result in variations of this adjustment factor. However, PCS activity variations outside of this morning fading period will not significantly effect availability interference statistics.

[13] CCIR, Propagation in Non-ionized Media, Volume V Annex, *Report 715-3*, "Propagation by Diffraction", Dusseldorf, 1990.

[14] G. Hufford, A. Longely, and W. Kissick, "A Guide to the Use of the ITS Irregular Terrain Model in the Area Prediction Mode", *NTIA Report 82-100* (PB 82-217977), April 1982.

[15] CCIR, Propagation in Non-ionized Media, Volume V Annex, Report 238-6, "Propagation Data and Prediction Methods Required for Terrestrial Tran-Horizon Systems", Dusseldorf, 1990.

or both the transmitter or receiver sites. This is what the Hata models[16] attempt to do on an average basis based on environmental descriptions such as medium-small city, large city, suburban, etc. For a conservative estimate of PCS to fixed microwave propagation close in, this annex recommends that the suburban Hata model be used with appropriate modifications discussed later. This document also recommends merging the suburban Hata model with the various transhorizon models at a distance determined by both the PCS and POFMS antenna heights.

### F-4.2 Smooth Earth Transition Distance

Since recommended coordination distances go out to 400 km, transmission over a large percentage of the path will be over the horizon as indicated in the figure below.

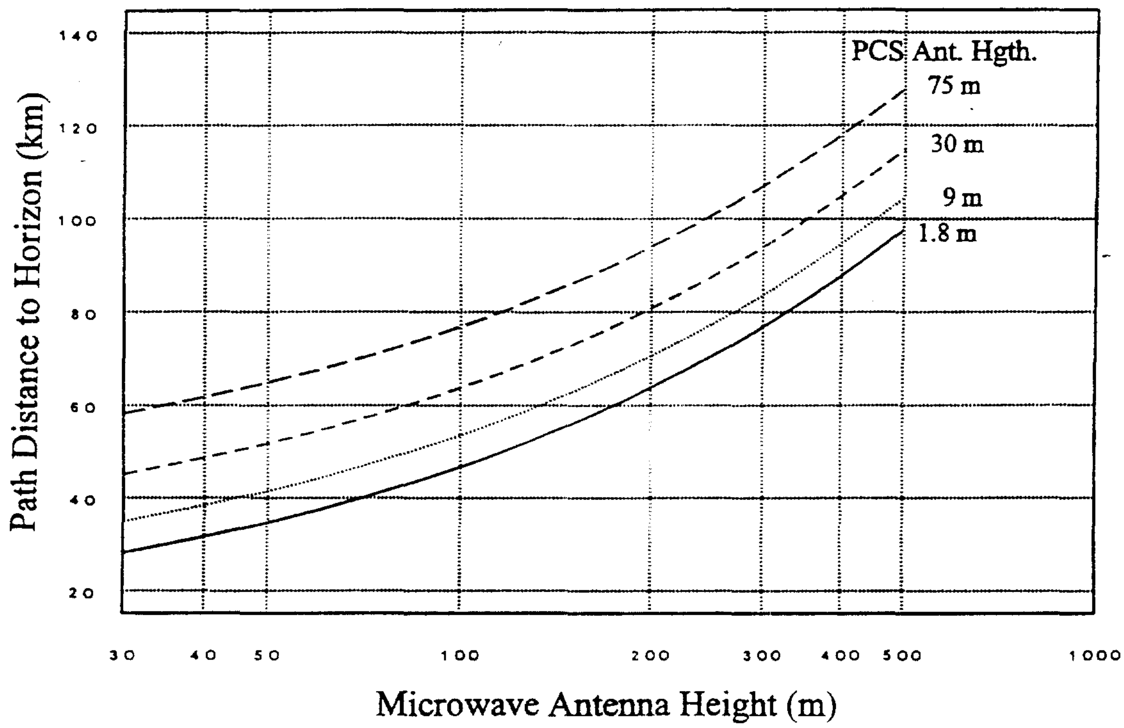


**Figure F-4-1 Smooth Earth Transition Distance vs. PCS Antenna Height**

This smooth earth transition distance depends on the receiver and transmitter antenna heights above the average elevation along the path. Assuming no intervening man-made or terrain obstacles, the sum of the

16 M. Hata, "Empirical formula for propagating loss in land mobile radio services", *IEEE Trans. VTS*, vol. 29, no. 3, pp. 317-325, August 1980.

distances to the common horizon for both transmitting and receiving antenna heights is given by:[17]

$$d_h = 4.123 \left( \sqrt{h_{pcs}} + \sqrt{h_{mw}} \right) \qquad \text{(F-4-1)}$$

where,

$d_h$ = Transition distance (km)

$h_{pcs}$ = PCS antenna height above average terrain along the path (meters). Use 1 meter for values less than 1 meter.

$h_{mw}$ = MW antenna height above average terrain along the path (meters). Use 1 meter for values less than 1 meter.

F-4.3 Forward Scatter Loss

For propagation beyond the transhorizon distance, a forward scatter (troposcatter) loss model is used. The recommended equation for forward scatter loss between isotropic antennas is from *CCIR Rep. 238-6*, Equations 1 – 6 and Tables 1 and 2,[18] which is reproduced below for hourly median loss.

$$L_{50} = 29.73 + 30\log(f) + 10\log(d) + 30\log(\theta) + N(H, h) \qquad \text{(F-4-2)}$$

where:

$L_{50}$ = Hourly median transmission loss 50% of the time (dB)

$f$ = Frequency (MHz)

$d$ = Path length (km)

$\theta$ = $(d - d_h) / 8.5$ (milliradian) — $d_h$ is defined in Equation F-4-1

$$N(H, h) = 20\log(5 + \gamma H) + 4.343\,\gamma h \qquad \text{(F-4-3)}$$

where:

$H$ = $\theta\, d / 4000$

$h$ = $1.063\ 10^{-3}\ \theta^2$

$\gamma$ = 0.27

Equation (F-4-2) is the estimated path loss for 50% of the time. For example, for 99.9% of the time, Equation (F-4-2) should be modified as shown:

$$L_{99.9} = L_{50} - 5.3 - (19.5 - 5.5\times 10^{-4} f)\exp(-145.6\times 10^{-6}\times \theta^2) \qquad \text{(F-4-4)}$$

[17] S. Shibuya, *A Basic Atlas of Radio-Wave Propagation*, John Wiley & Sons, 1987, Chapter 3, pp. 239-240.

[18] CCIR Report 238-6, "Propagation Data and Prediction Methods Required for Terrestrial Tran-Horizon Systems",CCIR, Volume V Annex – Propagation in Non-ionized Media, Dusseldorf, 1990.

Note that this is the loss between isotropic antennas. When transmit and receive antenna gains are used to calculate the received power at the victim antenna, the sum of the antenna gains must be reduced by the aperture to medium coupling loss given by:

$$L_c = 0.07 \exp\left[\, 0.055 \ (G_{pcs} + G_{mw}) \,\right] \tag{F-4-5}$$

where:

$L_c$ = aperture to medium coupling loss, dB
$G_{pcs}$ = the PCS antenna gain, dBi
$G_{mw}$ = the MW antenna gain, dBi

The mean receive level at the victim receiver would then be given by

$$P_{rec} = -L_{50} + G_{pcs}(\phi) + G_{mw}(\phi) + P_{xmt} - L_c \tag{F-4-6}$$

where:

$P_{rec}$ = the power at the victim receiver
$P_{xmt}$ = the power from the PCS transmitter
$G_{pcs}(\phi)$ = PCS antenna gain at the two dimensional discrimination angle $\phi$
$G_{mw}(\phi)$ = Microwave antenna gain at the two dimensional discrimination angle $\phi$

## F-4.4 Models

### F-4.4.1 PCS Mobile or Portable on the Ground to MW Site

For PCS mobile or Portable on the ground, the recommended loss model ($L_{pcs}$) up to a transition distance (to be discussed later) is the Hata medium-small city urban model with the suburban correction factor since studies have found that this provides a better fit for typical US cities: [19]

[19] IEEE VTS Committee on Radio Propagation, "Coverage Prediction for Mobile Radio Systems Operating in the 800/900 MHz Frequency Range", *IEEE Trans. VTS*, vol. 37, no. 1, page 24, February, 1988.

M. Hata, "Empirical formula for propagating loss in land mobile radio services", *IEEE Trans. VTS*, vol. 29, no. 3, pp. 317-325, August 1980.

$$
\begin{aligned}
L_{pcs} &= 69.55 + 26.16 \log(f) - 13.82 \log(h_{mw}) \\
&+ \left[ 44.9 - 6.55 \log(h_{mw}) \right] \log(d) - \alpha(h_{pcs}) \\
&- 2\left[ \log\left( \frac{f}{28} \right) \right]^2 - 5.4
\end{aligned}
\qquad \text{(F-4-7)}
$$

where:

$$\alpha(h_{pcs}) = [\, 1.1 \log(f) - 0.7 \,]\, h_{pcs} - [\, 1.56 \log(f) - 0.8 \,]$$

$L_{pcs}$ = Loss between PCS and MW antennas using the modified Hata model

Note that this model will be used past its recommended distance of 20 km. But it appears to give a better transition to the transhorizon forward scatter loss model. The CCIR extension of the Hata model[20] to 100 km appears to greatly overestimate propagation loss at the transhorizon transition as shown in Section F-4.4.4. Again, these are the mean losses with a typical standard deviation of 7.5 dB.

F-4.4.1.1 Statistical Adjustments to the Mean Hata Suburban Model

Measured data[21] shows trends that can be used to adjust the mean Hata suburban model for particular situations to estimate lower bound losses, for interference calculation purposes, from the street to a particular antenna site. The following suggested recommendations should be used to the transition distance defined in Equation F-4-12.

1) In downtown high rise core use the Hata mean suburban propagation loss model for the whole subscriber population.

2) In dense city areas without a lot of tall buildings use the Hata mean suburban propagation loss model for 93.5% of the subscriber population, adjust the model for one standard deviation less loss for 6% of the subscribers (use 7.5 dB for the standard deviation if it is not known) and adjust the model for 2.34 standard deviation less loss for 0.5% of the subscriber population.

[20] CCIR, Propagation in Non-ionized Media, Volume V Annex, Report 567-4, "Propagation Data and Prediction Methods for the Terrestrial Land Mobile Service using the Frequency Range 30 MHz to 3 GHz", Equation (9), Dusseldorf, 1990.

[21] Southwestern Bell Personal Communications Inc., Quarterly Progress Report Number One, File Number: 2195-EX-PL-91, June 17, 1992.

P. Vilmur, "Hata Suburban Model Compared to Urban and Suburban measurements", Submission to TIA TR14.11 Committee, TR14.11-28, May 6, 1993.

D.M. Devasirvatham and S.Y. Seidel, "Propagation Studies for Sharing Spectrum Between PCS and Fixed Microwave (OFS) System", TR14.11-92, January 25, 1994.

3) For low density suburban areas use the Hata mean suburban propagation loss model for 70% of the subscribers, the model adjusted for one standard deviation for 24.5% of the subscribers (use 6.0 dB for the standard deviation if it is not known), the model adjusted for 2.34 standard deviations for 5% of the subscribers and free space loss for 0.5% of the subscribers.

For convenience, the recommended adjustments above are incorporated as dB corrections in Figures F-4.2 and F-4.3 as a function of the standard deviation from mean path loss. Note that a particular example was used to generate these figures and that Figure F-4.3 is dependent on the distance used in the example because the Hata suburban model and the free space model have different loss slopes with distance. The example used to generate the Figure F-4.3 is given below:

$$P\,(total,\,mean) \;=\; N P_{sub}\, 10^{\left(\frac{-L}{10}\right)} \qquad \text{(F-4-8)}$$

where:

N = Number of users (1000 used)
$P_{sub}$ = Power of PCS Radio (1 watt used)
L = Mean Hata Suburban Loss (1.6 km used with 30 m Base antenna and 1.5 m Mobile antenna)

$$P_i \;=\; N P_{SUB}\, 10^{\left(\frac{-L}{10}\right)} \left[0.70 + 0.245\, 10^{\left(\frac{S}{10}\right)} + 0.05\, 10^{\left(\frac{2.58\,S}{10}\right)} + 0.005\, 10^{\left(\frac{-FSx}{10}\right)}\right] \qquad \text{(F-4-9)}$$

where

S = Standard Deviation, dB (Independent variable)
FSx = Excess Loss over Free Space, dB (1.6 km used)
L = Mean Hata Suburban Loss, dB (1.6 km used)

$$dB_{inc} \;=\; 10 \log\left(\frac{P_i}{P\,(total,\,mean)}\right)$$

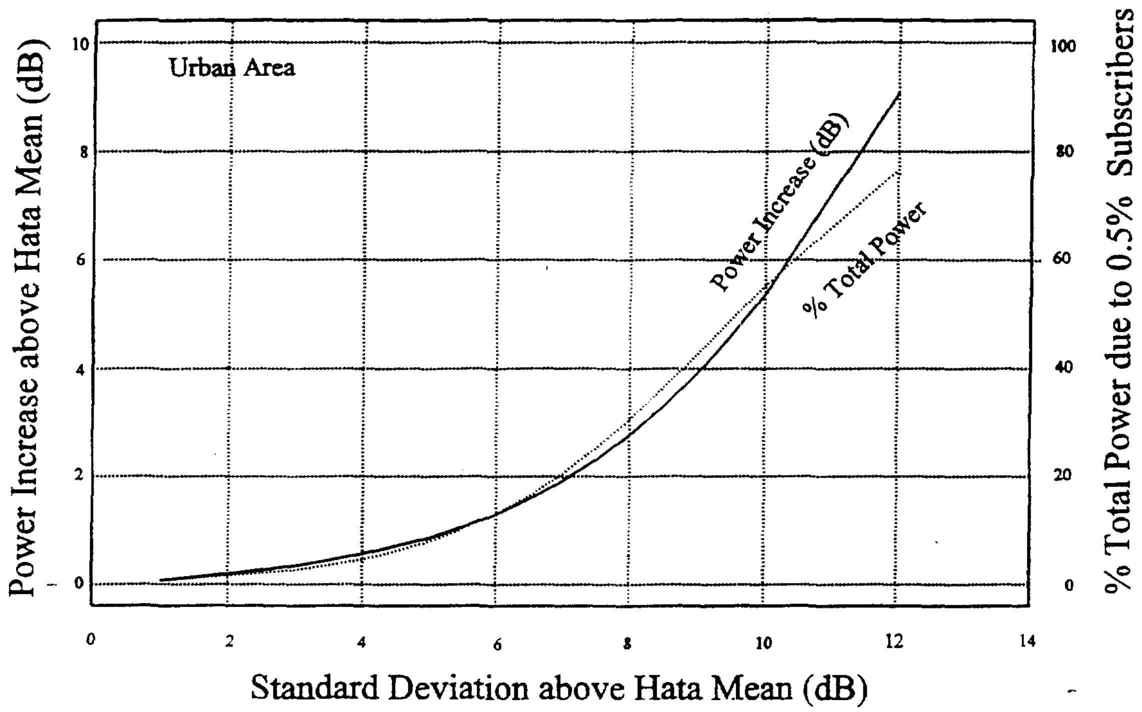


**Figure F-4.2 Power Increase above Hata Mean vs. Standard Deviation for Urban Environments**